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Combining control electronics with SOA to equalize packet-to-packet power variations for optical 3R regeneration in optical networks at 10 Gbit/s

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Abstract: We report on the combined effects of control electronics and a SOA as to suppress packet to packet power fluctuations. Associated to a SOA-MZI based 3R regenerator, we demonstrate a power dynamic range of 9dB.

OCIS codes: (250,5980) Semiconductor Optical Amplifier (999,9999) Power Equalization

1. Introduction

Since long optical technologies has been identified and investigated as an alternative to some of the key functionalities required in optical packet switching. This includes regeneration of the signal, as considered in this paper. When building flexible optical networks, it is a prerequisite that the switching nodes can be cascaded; hence the signal quality should be preserved when passing a switch. This is ensured by 3R regeneration interfaces, where the signal is re-amplified, re-shaped and re-timed. Several solutions for 3R regeneration have been proposed based on electrical and optical technologies [1, 2, 3]. Optical 3R regeneration based on semiconductor optical amplifiers (SOA) exploits the saturation effects in the SOA through cross-gain (XGM) or cross-phase modulation (XPM), but the operation of these devices is, however, dependent on the optical power. Hence, power equalization is mandatory before the regenerator or as an integrated part of the input interface to the 3R device. Even though 3R regeneration at 40 Gbit/s has attracted a lot of attention seen from a transmission perspective, it is still required to improve 10 Gbit/s regeneration design for switches in packet switched networks like, e.g., the network in the European IST project DAVID [4]. In a packet switched environment the power of the packets may vary for each packet depending on the source of the packet. This increases the requirements to a fast equalization system as to ensure the integrity of all the bits of the packet and more peculiarly the first bits. Semiconductor Optical Amplifier-based devices are sufficiently fast although their operational margins do not allow packet-to-packet power variation larger than 3-4dB. In [5], however, two SOAs were used to obtain a dynamic range of up to 8dB.

In this paper we present a power equalization scheme comprising a SOA in the saturation regime assisted by control electronics to increase the dynamic range and an optical 3R regenerator using a Mach Zender Interferometer (SOA-MZI). With such an association, we demonstrate a tolerance of 9dB at 10Gbit/s of the complete structure with respect to fast packet-to-packet power fluctuations.

2. Power equalization concept

The power equalization and signal regeneration structure is illustrated in Fig. 1.

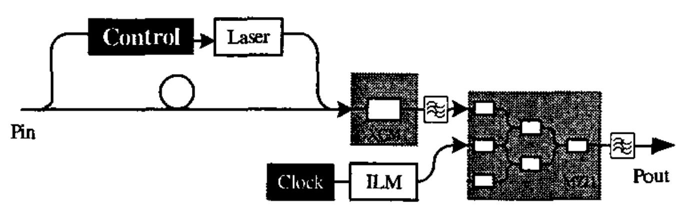


Fig. 1. Structure of the regenerator: Part of the incoming signal is used to control the probe power to the XGM

Part of the incoming optical power is tapped to the control electronics (CE), while the remaining is launched through a fiber delay line into the SOA in the saturation regime. The CE determines the power of the packet and controls the power of the DFB laser used as a probe signal for a SOA operating under cross-gain modulation regime (XGM). As described in [6], the DFB laser is intended to provide a power proportional to the power of the incoming packet. The role of the XGM is - beside to increase the operational margins – to act as a stabilization element to fix the polarization to the succeeding MZI structure. Finally a SOA-MZI operating in data inverting polarity mode or out-of-phase regenerates the signal not only in the amplitude domain but also in the time domain using as a probe signal a synchronized optical clock. The regenerative capabilities of such a structure can be improved by using a double SOA-MZI cascade while preserving a high bit rate potential as shown in [7] with the demonstration of a 3R regeneration experiment at 40Gbit/s. As to confirm the potential of such regeneration structure, the combination SOA-XGM+SOA-MZI has allowed the demonstration of 43Gbit/s FEC-compatible RZ transmission with regenerative capabilities in WDM environment (5 channels with channel spacing of 200 GHz) over 30,000km [7].

3. Control electronics

The control electronic (CE) is responsible for tracking the power of the incoming optical packets. This enables it to control the output power of the laser that acts as probe power source for the XGM. The requirements to the CE are, besides tracking the input power, ability to control the probe laser independent whether the nature of the optical power source is a DFB laser or an Integrated Laser Modulator-ILM. As to match with all these requirements, the core of the CE was built digitally. The block-diagram for the CE is given in Fig. 2.

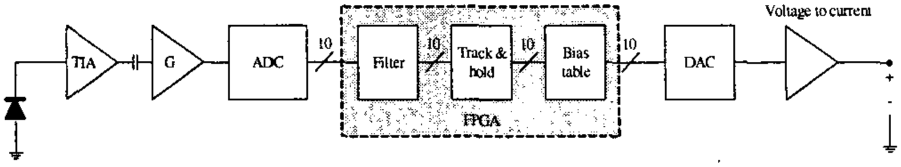
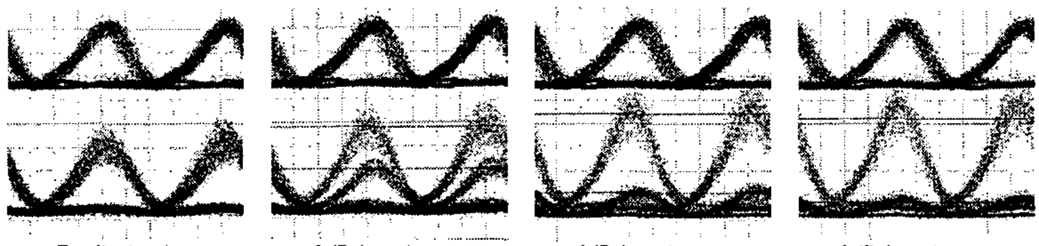


Fig. 2. Block-diagram of control electronics

The optical signal is received and amplified in the low noise trans-impedance amplifier (TIA) and a low pass amplifier to allow an envelope of the signal to the ADC circuit. The digital block comprises a low pass filter, a track and hold detection circuit and a bias table to adapt to any laser transfer function at the output. The rest of the CE converts the signal back to the analog domain to deliver a current-signal to the probe laser. The CE design has several advantages. First, the digital core allows interfacing to any ILM or DFB laser, as only the bias table has to be changed. Secondly, switching the probe current is done within a single clock-cycle, which fits well within the guard band (GB) between two packets. Thirdly, the digital design is robust and stable towards changes in temperature etc.

4. Experimental setup and results

The operation of the scheme was verified in an environment with packet-to-packet power-variations. Half the 10Gbit/s packets of each 1μs were attenuated to generate the desired dynamic range. Eye-diagrams recorded at the output of the SOA-MZI are shown in for different imbalances in power between consecutive packets and with the CE in operation.



Equalized packets 3 dB dynamic range 6 dB dynamic range 9 dB dynamic range

Fig. 3. Eye-diagrams for the input (lower) and the output (upper) for different variations in the packet-to-packet power level.

As seen from Fig. 3, the output of the SOA-MZI stage is independent of the variation in the packet-to-packet power of up to 9dB. These results are further fully validated through BER measurements as depicted in Fig. 5. A power penalty of approximately 2.5 dB is observed between equalized packets and packets with a power variation of 9dB. Furthermore, no BER floor is observed in any of the measurements, while it is believed that the reduction of the slope for some of the measurements is due to the receiver.

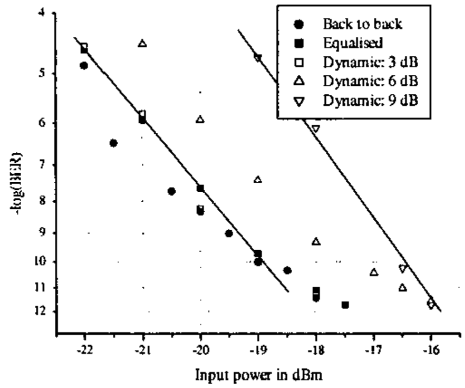


Fig. 5. BER measurements with back to back and different dynamic ranges of the incoming power level

It is noted that the first 20-30 bits of each packet were masked as a consequence of the operation features of the burst receiver used during our measurements. The trace reported in (a) detailing the first bits of the packet preamble clearly demonstrate that the integrity of these first bits is preserved.

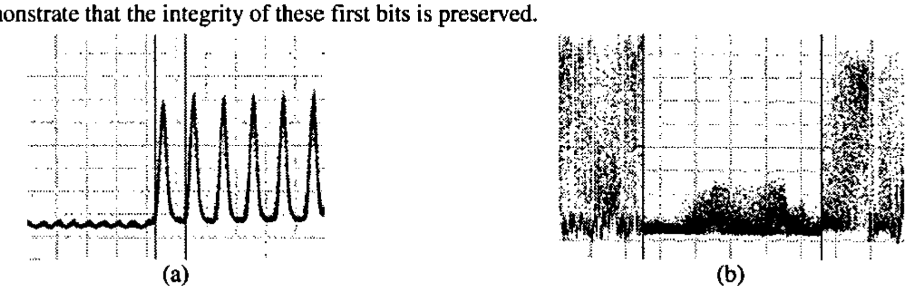


Fig. 6. The guard-band (a) and the preamble of the equalized packet (b) with a dynamic range of approximately 4 dB. The GB in (a) has a duration of 51 ns, while the preamble in (b) has the time-scale of 200 ps. pr. division.

However, an examination of the guard-band (GB) separating consecutive packets reveals the appearance of distortions coming from clock pulse residue. A solution to suppress this effect is the use of a "switched clock" for the re-timing stage, which is a signal without clock pulse at duration equal to GB. This can simply be done by logic AND between the clock signal to SOA-MZI and a GB suppressing signal.

5. Conclusion

In this paper we have investigated the association of cross-gain modulation (XGM) in a semiconductor Optical Amplifier with low cost electronics for equalizing packet-to-packet power variations, which is a prerequisite for any regenerative systems (optical or electrical). The control electronics (CE) determines the power level and controls the probe power to the XGM. The CE was designed with a digital core, which allows for high flexibility and fast switching while ensuring a robust design. With the CE in operation a power equalization of 9dB was obtained with no BER floor and a power penalty of only 2.5dB in connection with an optical SOA-MZI based 3R regenerator.

6. Acknowledgement

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